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The influence of pouring temperature on the microstructure and fluidity of AE42 alloy

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ABSTRACT

Purpose: The automotive use of magnesium is currently restricted to low-temperature structural components. Rare earth additions such as Ce, Nd, La and Pr are known to improve the creep performance. The aim of the research was to determine the effect of pouring temperature on the as-cast microstructure of AE42 magnesium alloy.

Design/methodology/approach: The study was conducted on Mg-4Al-2RE (AE42) alloy after cast in different conditions. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). The phase composition of these alloys was identified by X-ray diffraction (JDX-75). A program for image analysis "MET-ILO" was used for determination of area fraction of intermetallic phases.

Findings: The microstructure of AE42 alloy consists of α-Mg solid solution with divorced eutectic $Mg_{17}Al_{12}$ + α-Mg, $Al_{11}RE_3$ and Al_8REMn_4. Pouring temperature has an influence on the fluidity and microstructure.

Research limitations/implications: The future research will contain creep tests and microstructural investigations of cast and die-cast alloys using TEM microscopy.

Practical implications: Results of investigation may be useful for preparation of sand casting technology of the Mg-Al-RE alloys.

Originality/value: This paper includes the results of microstructural investigations and effects of pouring temperature on the fluidity of AE42 magnesium alloy for gravity casting technology.

Keywords: Metallic alloys; Magnesium-Aluminum-Rare Earth Alloys; Microstructure

MATERIALS

1. Introduction

Magnesium alloys with their weight advantage have unique application opportunities in the automotive industry [1-4]. Typical microstructure of Mg-Al alloys is composed of α-Mg matrix, $Mg_{17}Al_{12}$ precipitations and small volume of Al_8Mn_5 phase. However, their applications are restricted when the temperature surpasses 120 °C, due to instability of β-$Mg_{17}Al_{12}$ phase [2-5]. A casting alloy that was developed for high temperature applications is AE42 (Mg-4Al-2RE). Aluminum is added to improve castability and room temperature mechanical properties and RE for creep resistance. However, the properties of AE42 deteriorate rapidly when the temperature is above 150 °C [6]. At this temperature a partial decomposition of Al_{11}RE3 had been reported [7-8]. This leads to the emerging of β phase, which is attributed to the deterioration of creep resistance. Therefore a limitation to the use of AE42 magnesium alloys at high temperature still remains. The increasing of RE content can cause the improvement of creep resistance [7]. With an increasing RE/Al ratio, Al_2RE phase gradually becomes more dominant phase in relation to $Al_{11}RE_3$. A higher RE content than that of AE42, possibly producing Al_2RE phase during solidification, this unwanted phase transformation may no longer occur [8-15]. Present study has focused on the effect of pouring temperature on the microstructure and fluidity of AE42 alloy.

2. Experiment

Sand casts of AE42 alloy with the chemical composition 4Al-0.5Mn-2RE-0.05Si were investigated. The rare earth additions were made as mischmetal with the approximate compositions: 50Ce-25La-20Nd-3Pr.

Fluidity has been investigated by determination of the flow length with a mould featuring a spiral shaped cavity. The shape of fluidity spiral is shown in Fig.1. Casting in sand moulds has been done at different melt temperature from 695°C up to 755 °C.

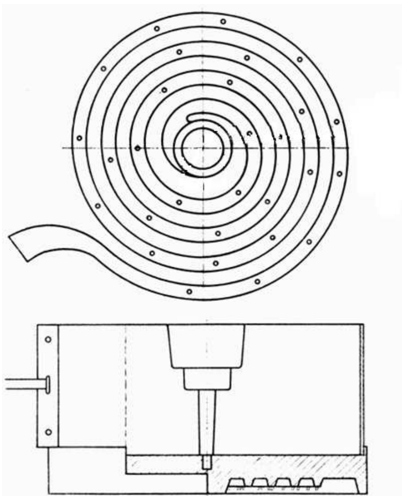


Fig. 1. Drawing of spiral sample to investigate the fluidity

Specimens for microstructural studies were mechanically polished using standard methods and etched with 5% acetic acid. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an EDS detector (VOYAGER of NORAN INSTRUMENTS). EDS analysis was performed with an accelerating voltage of 15 keV. The phase identification of these alloys was conducted by X-ray diffraction (JDX-75) using Cu Kα radiation. A program for image analysis "MET-ILO" was used for determination of the area fraction of intermetallic phases.

3. Results and discussion

3.1. Microstructure of sand cast AE42 alloy

Microstructures of AE42 alloy under optical microscope are showed in Fig. 2. There were observed the α-Mg matrix, divorced eutectic and few kinds of precipitations. Moreover, in the vicinity of an eutectic, the matrix is etched more than in central part of the grain. It suggests the segregation of chemical composition inside of the grains. The XRD pattern of AE42 indicates that this alloy is mainly composed of α-Mg phase and $Mg_{17}Al_{12}$ phase (Fig. 3). The intensities of α-Mg peaks are not proportional to the data from JCPDS standard, indicating the absence random distribution of grain orientations. The other diffraction lines were identified as Al_8REMn_4 and $Al_{11}RE_3$, however the intensity of these reflections is low and their identification must be confirmed by others methods (e.g. TEM).

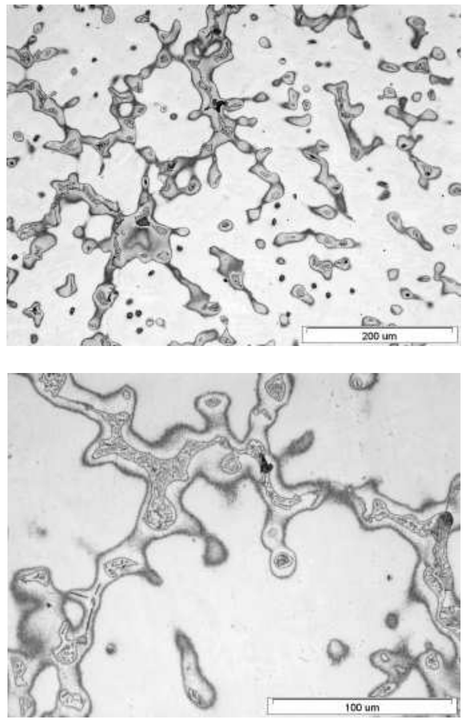


Fig. 2. LM microstructure of as-cast AE42 alloy after sand casting at 735 °C

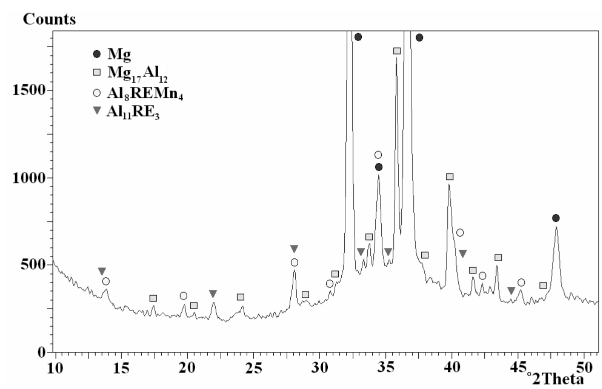


Fig. 3. X-ray diffraction pattern of AE42 alloy

Further SEM observation indicates divorced eutectic characteristic (α-Mg+$Mg_{17}Al_{12}$), as one may notice in Fig. 4 (point A). Additionally, the lamellar precipitates of $Mg_{17}Al_{12}$ are present mostly in the α-Mg regions, near the eutectic phase, hence these regions have higher aluminum content (point B). The aluminum content (point C, Tab. 1) in solid solution α-Mg is higher than its maximal solubility at ambient temperature. In regions of matrix near to eutectic, which do not contain lamellar $Mg_{17}Al_{12}$ phase (point D), the aluminum concentration is much higher than in the centres of the dendrites.

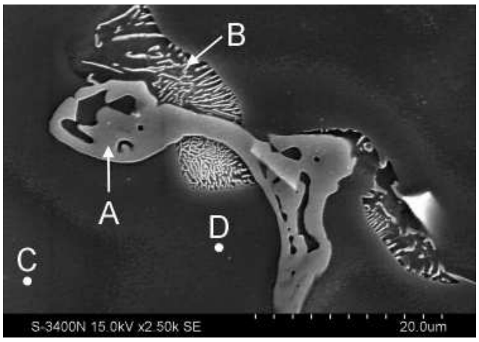


Fig. 4. SE image of AE42 alloy after casting from 735 °C

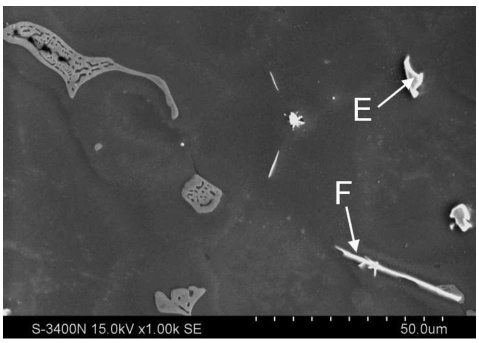


Fig. 5. SE image of AE42 alloy after casting at 735 °C

Table 1.
Element distribution in different areas of AE42 as-cast structure from Fig. 4 and 5 (at.%)

Point	Mg-K	Al-K	Ce-L	La-L	Nd-L	Mn-K
A	66.3	33.7	-	-	-	-
B	86.5	13.5				-
C	98.4	1.6	-	-	-	-
D	90.2	9.8				
E	5.6	57.3	3.3	-	0.9	32.9
F	10.9	73.2	4.8	10.2	0.9	-

Moreover, EDS analysis reveals that the microstructure contains irregular Mn-rich phase, which can correspond to Al_8REMn_4, and needle shaped RE-rich phases – $Al_{11}RE_3$ (points E and F respectively, Fig. 5, Tab. 1). Precipitates of Al_8REMn_4 are present in grains of solid solution, whereas particles of $Al_{11}RE_3$ are found in center of grains and eutectic regions.

3.2. Influence of pouring temperature on the fluidity

Figures 6 and 7 show the influence of pouring temperature on the fluidity of AE42 alloy. When pouring temperature is at 755 °C, the fluidity length of AE42 alloy is 0.44 m and decreases to 0.21 m only at 695 °C. The filling length increases slowly when the casting temperature increases from 695 °C to 715 °C, but increases rapidly when the pouring temperature is higher than 715 °C. If the casting temperature increases from 735 °C to 755 °C, the rate of fluidity growth is lower again.

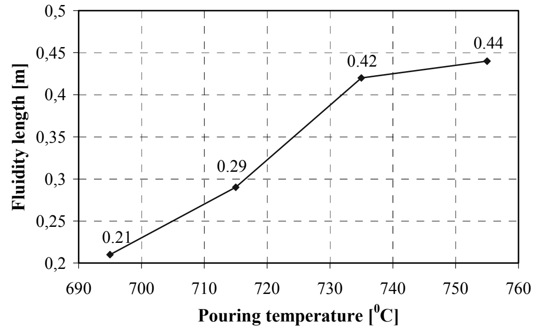
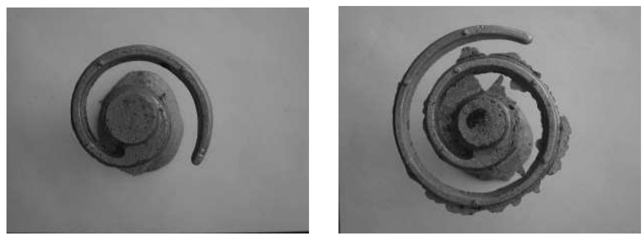


Fig. 6. The influence of casting temperature on the fluidity length



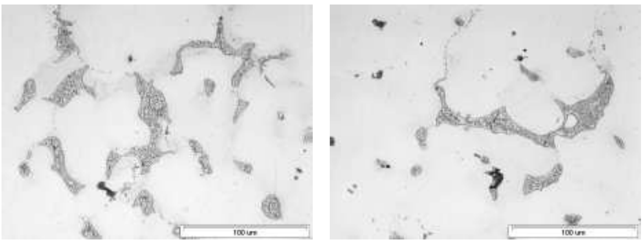
a) b)

Fig. 7. Spiral cast of AE42 alloy poured at the temperature of 695°C (a) and 795°C (b)

Generally, a better fluidity in higher temperature is connected with the decreasing viscosity and surface tension of molten metal with the increasing of pouring temperature, which leads to the increasing filling speed. At the same time, the heat capacity of molten magnesium alloy rises with increasing temperature of the pouring, what results in the increase of filling time. On the other hand, the oxidation liability of magnesium alloy increases with the pouring temperature rise, what increases the viscosity and decreases the filling speed [13]. Therefore, growth rate of fluidity above 735 °C is lower than between 695 °C and 735 °C.

3.3. The influence of pouring temperature on the microstructure

Microstructures of AE42 alloy after casting to sand mould are shown in Fig. 8. Generally, phase composition of alloy is the same after casting at different temperatures. Table 2 shows, the variation of the intermetallic phases fraction as a function of pouring temperature and associated standard deviation. One can see in the Table 2, that the area fraction of divorced eutectic increases slightly with the increase of the pouring temperature within the range studied here. Higher pouring temperature results in higher eutectic starting temperature and in decrease of the undercooling for eutectic reaction. It leads to higher concentration of eutectic during casting from higher temperature.



a) b)

Fig. 8. Microstructure after casting at 735 °C (a) and at 695 °C (b). Specimens were slightly etched in glycol without revealed of supersaturation regions

Table 2.
The area fraction of intermetallic compounds after casting from different temperatures

Phase	Unit	Temperature, °C			
		695	715	735	755
$Mg_{17}Al_{12}$ eutectic	%	1.98 ±0.33	2.13 ±0.29	2,92 ±0.26	3,14 ±0.21
Discontinuous $Mg_{17}Al_{12}$	%	0.78 ±0.16	0.82 ±0.19	0.99 ±0.11	1.09 ±0.10
$Al_{11}RE_3$	%	0.68 ±0.12	0.74 ±0.11	0.72 ±0.15	0.73 ±0.10
Al_8REMn_4	%	0.82 ±0.18	0.83 ±0.09	0.85 ±0.11	0.79 ±0.12
Inclusions with Si and O	%	0.52 ±0.29	0.70 ±0.21	0.83 ±0.16	0.96 ±0.11

However this interpretation is not unequivocal and will be object further examinations. The area fraction of discontinuous $Mg_{17}Al_{12}$ rises with the increasing of the casting temperature. The inclusion concentration containing oxide and silicon increase due to higher reactivity of molten metal and mould. In case of $Al_{11}RE_3$ and Al_8REMn_4 the relationship between temperature and area fraction was not observed. Moreover, in specimens poured at lower temperature more of non-uniform structure was observed than in case of pouring at higher temperature. More detailed analysis of the influence of pouring temperature on the volume fraction, grain size, chemical composition of solid solution and precipitates will be published later.

4. Conclusions

Based on the research results obtained, it has been found that:

(1) The as-cast microstructure of sand cast AE42 alloy is mainly composed of α-Mg matrix and $Mg_{17}Al_{12}$. Additionally the presence of $Al_{11}RE_3$ and Al_8REMn_4 was found.
(2) The increase of pouring temperature results in the increase of the fluidity.
(3) The decrease of pouring temperature results in the decrease of divorced eutectic, discontinuous precipitates of $Mg_{17}Al_{12}$ and inclusions area fraction.
(4) The change of pouring temperature has no influence on the $Al_{11}RE_3$ and Al_8REMn_4 area fraction.

Acknowledgements

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